EEMS044

JUNE 3RD, 2020

QUANTIFICATION OF NATIONAL ENERGY IMPACTS OF ELECTRIFIED SHARED MOBILITY WITH INFRASTRUCTURE SUPPORT

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OVERVIEW

Timeline

- Project start date: October 1. 2017
- Project end date: September 30, 2019
- Percent complete: 100%

Barriers

- Aggregate limited regional results to national
- Accurately measuring the transportation system-wide energy impacts of advanced fueling infrastructure supporting mobility of service (e.g. ride-hailing)

Budget

- Total project funding:
  - DOE share: 100%
  - Contractor share: 0%
- Funding for FY 2018: $250,000
- Funding for FY 2019: $500,000

Partners / Collaboration

- ANL (lead) – Yan (Joann) Zhou (PI), Zicheng (Kevin) Bi
- Oak Ridge National Laboratory (Fei Xie)
- National Renewable Energy Laboratory (Eric Wood, Dong-Yeon Lee)
- Coordination with SMART AFI Task 2

RELEVANCE

- **Overall objectives:**
  - Quantify the national energy impact of Ride-hailing Plug-in Electric Vehicles (PEVs) as compared with privately owned PEVs and ride-hailing ICEVs with varying infrastructure support (e.g. Level 2, DCFC, high power FC)
  - Mathematically:

    National Energy Impact = f (# of ride-hailing vehicles, PEV market penetrations)

- **Impact:**
  - Understand changes in petroleum and electricity consumption while providing mobility as a service (e.g. ride-hailing) using electrification supported by infrastructure.
  - Complements workflow by quantifying energy consumption of using charging infrastructure to support electrified ride-hailing at national level

FY19 OBJECTIVES AND MILESTONES

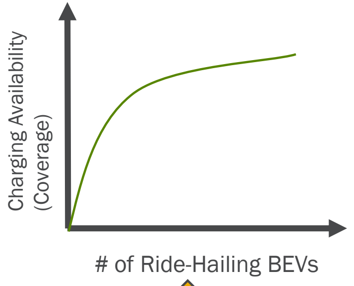
- Enhance the method that expands on regional EVSE deployment findings (AFI task 2) to understand national PEV market adoptions
- Quantify reduction in national energy consumption considering different levels of ride-hailing usage and electric vehicle demand in ride-hailing fleet.
- Analyze trade-offs between fast charging infrastructure and number of electrified shared vehicles needed and estimate national energy impacts

Date	Type	Milestones Go/No-Go	Status
12/31/2019	Quarterly	Report on national energy impact of different scenarios (ANL)	Complete
3/31/2019	Quarterly	Presentation on regional results (NREL)	Complete
6/30/2019	Quarterly	Presentation on market penetration scenario analysis (ORNL)	Complete
9/30/2019	Annual	Report on updated national energy impact and sensitivity analysis (ANL)	Complete

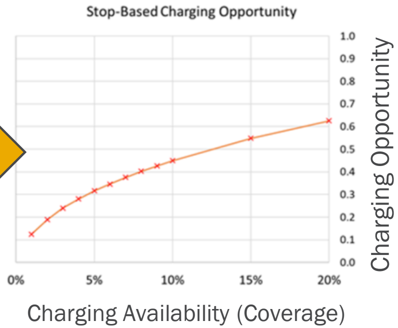
APPROACH

Identify the charging opportunity for given # of ride-hailing (RH) BEVs

Step 1 (FY19 main focus) (slides 6-9)

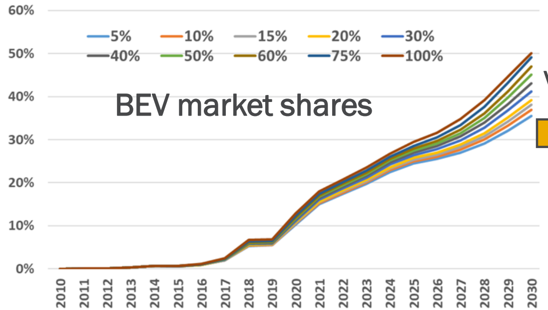


Step 2 (slide 10)



ORNL MA3T

Step 3 (slide 10)



ANL VISION

Results (slide 11-13)

National Energy Impact

Total VMT * RH Demand * BEV% in RH

Charging Availability: % of area or covered by at least one charger

Charging Opportunity: % of trips end in the locations with at least one charger

Two approaches:

- **Top-down approach: based on probability and statistics (FY19 Focus, slide 6-9, Step 1.1 to 1.4)**
  - Mathematically identify the number of chargers needed with a given ride-hailing BEV fleet size and charging demand, **based on probability and statistics**
  - Data: Census data, Household Travel Survey
- Bottom-up approach: based on regional simulation (FY17-18 focus)

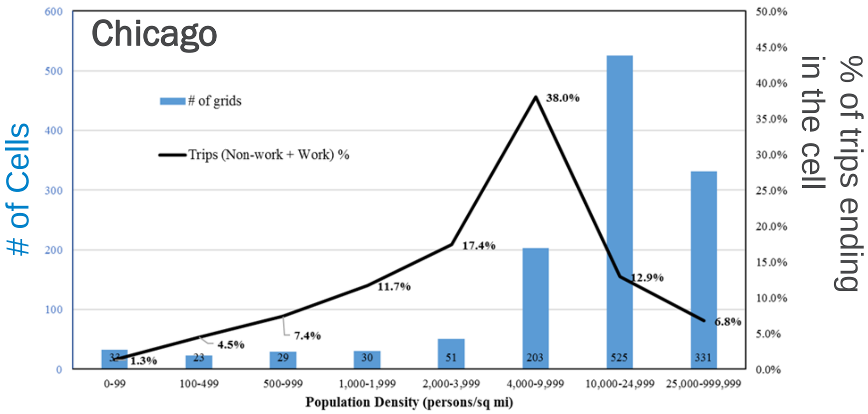
APPROACH

Determine # of chargers as a function of ride-hailing BEV fleet size

Step 1.1 # of trip stops → Step 1.2 Charging probability → Number of charging events → Step 1.3 # of chargers → Step 1.4 Charger coverage

Step 1.1: Quantify the number of daily trip stops in urban areas: Chicago (example)

- Urban area is divided into grid cells (0.25 × 0.25 mile per cell) by population density



$$Trips\ per\ cell = Total\ trips \times \frac{Trips\%}{\#\ of\ cells}$$

- Estimate the number of trip stops for each population density segment with given assumptions of % of trips served by ride-hailing BEVs:

Number of daily trip stops:

Population Density (persons/sq mi)		0-99	100-499	500-999	1,000-1,999	2,000-3,999	4,000-9,999	10,000-24,999	25,000-999,999
% of trips served by ride-hailing BEVs	0.10%	1	5	6	10	8	5	1	1
	1%	10	48	63	97	85	46	6	5
	5%	49	242	316	483	423	232	30	25
	10%	98	485	632	967	846	464	61	51
	25%	244	1212	1581	2416	2114	1160	152	127
	50%	488	2425	3162	4833	4228	2320	304	255
	75%	732	3637	4743	7249	6342	3480	457	382
	100%	976	4849	6324	9666	8456	4639	609	509

APPROACH

Determine # of chargers as a function of ride-hailing BEV fleet size

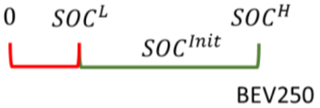
Step 1.1 # of trip stops → Step 1.2 Charging probability → Number of charging events → Step 1.3 # of chargers → Step 1.4 Charger coverage

Step 1.2: Assess charging probability based on distribution of battery state of charge (SOC) and average trip distance

$$\overbrace{P_1 + P_2 + P_3}^{\text{Infeasible}} + \overbrace{P_4 + P_5}^{\text{Feasible}} = 1$$

Need charge No charge needed

End of trip battery SOC:



Infeasible trips: The probability of services not taken P_1+P_2+P_3

P_1: Initial SOC < SOC^L
P_2: Initial SOC > SOC^L, but deadheading make it < 0%
P_3: Initial SOC + deadheading trip > SOC^L, but passenger trip make it < 0%

Feasible trips: The probability of recharging at end of trip: $P^{charge} = P_4 / (P_4+P_5)$

P_4: Initial SOC + deadheading + passenger trip > SOC^L, ending SOC < SOC^L
P_5: Initial SOC + deadheading + passenger trip > SOC^L, ending SOC > SOC^L

We used BEV250 with 150kw charging as the example for later analysis

APPROACH

Determine # of chargers as a function of ride-hailing BEV fleet size

Step 1.1 # of trip stops → Step 1.2 Charging probability → Number of charging events → Step 1.3 # of chargers → Step 1.4 Charger coverage

Step 1.3: Estimate the required number of chargers

- Multi-server queueing model
  Denoted as M/M/c queuing model
  - M: the arrival process is Poisson
  - M: the service times are exponential
  - c: the number of servers (i.e., chargers)

- Determine number of chargers X_i by **finding the minimum number of station size to satisfy the equation**

$$X_i = inf\{X|\underbrace{Pr(waiting\ time \leq \alpha)}_{\text{Probability of BEV to find available charger within waiting time } \alpha} \geq \beta\}$$

Probability of BEV to find available charger within waiting time α

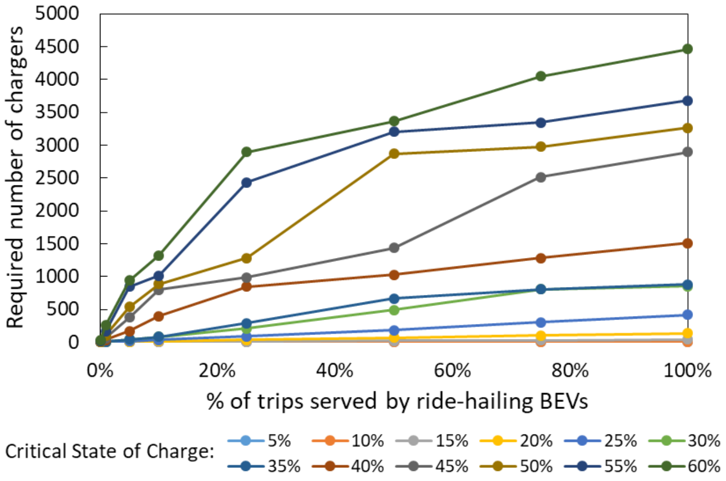
APPROACH

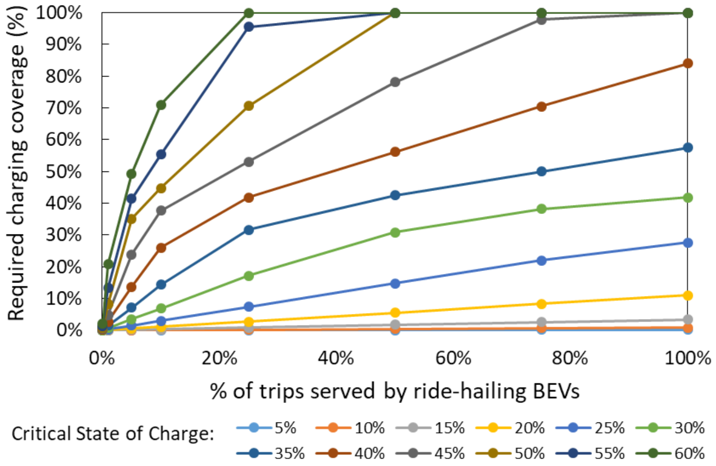
Determine # of chargers as a function of ride-hailing BEV fleet size

Step 1.1 # of trip stops → Step 1.2 Charging probability → Number of charging events → Step 1.3 # of chargers → Step 1.4 Charger coverage

Step 1.4: Characterize the charging coverage as a function of percentage of total passenger vehicle trips served by ride-hailing BEVs, at different assumptions of critical battery SOC levels.

Required # of chargers and charging coverage grows non-linearly with respect to ride-hailing BEVs. A higher assumption of critical SOC (e.g., 60%) leads to “earlier saturation” of chargers and coverage.



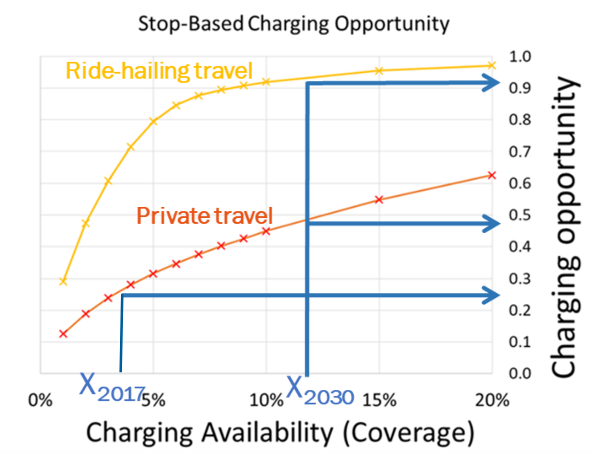


TECHNICAL ACCOMPLISHMENTS

Private BEV market shares with different charging opportunity levels

Step 2: Quantify Charging Opportunity

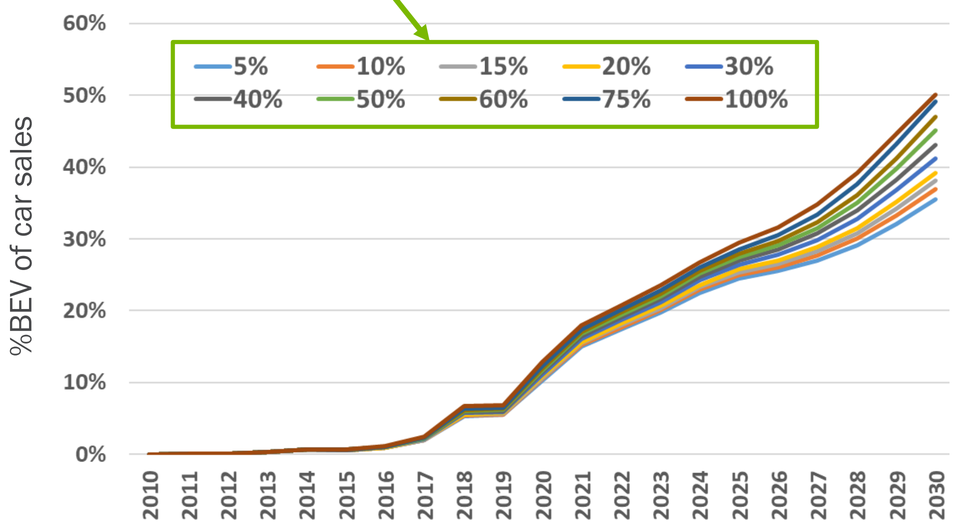
FY 18 work developed the following relationship between charging coverage and opportunity



(From step 1)

Step 3: Project Private BEV Market Penetration

Under different **charging opportunity** conditions



TECHNICAL ACCOMPLISHMENTS

National energy impact in 2030, compared to base case

This figure shows: (1) impact of ride-hailing and BEV penetration
(2) impact of deadheading

Energy:

With charging infrastructure growth

Ride-hailing battery electric vehicle sales % 2030: (columns); Ride-hailing demand (rows)

Ride-hailing demand	18%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	74%	Personal-use BEV sales share	Total VMT (billion)	RH VMT (billion)	Total Sales (thousand)	Deadheading Percentage
0.29%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	[43.8% , 43.8%]	3132	11	15730	49%
5%	0.9%	0.7%	0.6%	0.5%	0.4%	0.3%	0.2%	0.1%	0.0%	-0.1%	-0.2%	-0.3%	[43.8% , 43.8%]	3210	190	15956	47%
10%	2.7%	2.4%	2.2%	2.0%	1.8%	1.6%	1.4%	1.2%	1.0%	0.8%	0.6%	0.4%	[43.8% , 43.8%]	3279	365	16132	45%
15%	4.1%	3.7%	3.4%	3.1%	2.8%	2.5%	2.3%	2.0%	1.7%	1.4%	1.1%	0.9%	[43.8% , 43.8%]	3334	526	16252	42%
20%	5.2%	4.7%	4.3%	3.9%	3.6%	3.2%	2.8%	2.4%	2.0%	1.6%	1.2%	0.8%	[43.8% , 45.4%]	3377	676	16320	40%
25%	5.9%	5.3%	4.9%	4.4%	4.0%	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%	0.6%	[43.8% , 46.8%]	3410	815	16343	38%
30%	6.4%	5.7%	5.2%	4.7%	4.1%	3.5%	3.0%	2.4%	1.8%	1.2%	0.7%	0.2%	[43.8% , 47.9%]	3433	944	16325	36%
35%	6.7%	5.9%	5.3%	4.7%	4.0%	3.3%	2.7%	2.1%	1.4%	0.8%	0.2%	-0.4%	[43.8% , 48.8%]	3448	1065	16270	34%
40%	6.7%	5.8%	5.1%	4.4%	3.7%	3.0%	2.3%	1.6%	0.9%	0.2%	-0.5%	-1.1%	[43.8% , 49.5%]	3455	1178	16183	31%
45%	6.5%	5.5%	4.7%	4.0%	3.2%	2.4%	1.7%	0.9%	0.2%	-0.6%	-1.3%	-1.9%	[43.8% , 50.1%]	3455	1284	16065	29%
50%	6.1%	5.0%	4.2%	3.4%	2.5%	1.7%	0.9%	0.1%	-0.7%	-1.5%	-2.3%	-2.9%	[43.8% , 50.5%]	3448	1384	15919	27%
55%	5.6%	4.4%	3.5%	2.6%	1.8%	0.9%	0.0%	-0.8%	-1.6%	-2.5%	-3.3%	-4.0%	[43.8% , 51.0%]	3436	1477	15749	25%
60%	4.9%	3.6%	2.7%	1.8%	0.8%	-0.1%	-1.0%	-1.8%	-2.7%	-3.6%	-4.5%	-5.2%	[43.8% , 51.2%]	3418	1566	15556	23%
65%	4.0%	2.7%	1.7%	0.8%	-0.2%	-1.1%	-2.1%	-3.0%	-3.9%	-4.9%	-5.8%	-6.5%	[44.0% , 51.3%]	3395	1649	15342	20%
70%	3.0%	1.6%	0.6%	-0.3%	-1.3%	-2.3%	-3.3%	-4.3%	-5.2%	-6.2%	-7.2%	-7.9%	[44.5% , 51.5%]	3368	1728	15108	18%
75%	1.9%	0.5%	-0.5%	-1.6%	-2.6%	-3.6%	-4.6%	-5.6%	-6.6%	-7.6%	-8.6%	-9.4%	[44.9% , 51.6%]	3337	1803	14857	16%
80%	0.7%	-0.7%	-1.8%	-2.9%	-3.9%	-5.0%	-6.0%	-7.1%	-8.1%	-9.2%	-10.2%	-11.0%	[45.3% , 51.7%]	3302	1874	14590	14%
85%	-0.6%	-2.1%	-3.2%	-4.3%	-5.4%	-6.4%	-7.5%	-8.6%	-9.7%	-10.8%	-11.8%	-12.7%	[45.6% , 51.8%]	3263	1942	14307	11%
90%	-2.0%	-3.5%	-4.6%	-5.7%	-6.9%	-8.0%	-9.1%	-10.2%	-11.3%	-12.4%	-13.5%	-14.4%	[46.0% , 51.9%]	3221	2006	14011	9%
95%	-3.5%	-5.0%	-6.2%	-7.3%	-8.5%	-9.6%	-10.7%	-11.9%	-13.0%	-14.2%	-15.3%	-16.2%	[46.3% , 52.0%]	3176	2067	13701	7%
100%	-5.0%	-6.6%	-7.8%	-8.9%	-10.1%	-11.3%	$\boxed{-12.5\%}$	-13.6%	-14.8%	-16.0%	-17.2%	-18.1%	[46.7% , 52.0%]	3128	2125	13379	5%

Green: reduction
Red: increase
Yellow: relatively unchanged

Note: base case (without infrastructure) are shown in slide 22
Top-down approach results (FY18 work) are shown in slide 24

- **Impact of charging infrastructure alone is small: 1%–2% reduction**
- **Impact of faster fleet turn-over (due to ride-hailing) and BEV penetration: up to 18.1% reduction**
- **Deadheading may compromise the benefits**
- **$\boxed{\text{Results}}$ from two approaches are similar (within 5%)**

TECHNICAL ACCOMPLISHMENTS

Gasoline and electricity consumption (quads) in 2030

(a) Gasoline:

Ride-hailing demand	Ride-hailing battery electric vehicle stock % 2030: 12%	16%	19%	22%	26%	29%	32%	35%	38%	42%	45%	47%
	Ride-hailing battery electric vehicle sales % 2030: 18%	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**	**55%**	**60%**	**65%**	**70%**	**74%**
0.29%	10.24	10.24	10.24	10.24	10.24	10.24	10.23	10.23	10.23	10.23	10.23	10.23
5%	10.47	10.43	10.41	10.39	10.37	10.34	10.32	10.30	10.27	10.25	10.23	10.21
10%	10.66	10.60	10.55	10.51	10.46	10.42	10.38	10.33	10.29	10.24	10.20	10.16
15%	10.81	10.72	10.66	10.60	10.53	10.47	10.40	10.34	10.27	10.21	10.15	10.09
20%	10.93	10.82	10.74	10.65	10.57	10.49	10.40	10.32	10.23	10.14	10.04	9.97
25%	11.02	10.88	10.78	10.68	10.58	10.48	10.37	10.26	10.14	10.03	9.92	9.84
30%	11.07	10.92	10.80	10.69	10.56	10.43	10.30	10.18	10.05	9.92	9.80	9.70
35%	11.10	10.93	10.80	10.66	10.51	10.37	10.22	10.08	9.94	9.80	9.66	9.55
40%	11.11	10.92	10.77	10.61	10.45	10.29	10.13	9.98	9.82	9.67	9.52	9.40
45%	11.10	10.89	10.71	10.54	10.37	10.20	10.03	9.86	9.70	9.53	9.37	9.24
50%	11.07	10.83	10.64	10.46	10.28	10.10	9.92	9.74	9.56	9.39	9.21	9.07
55%	11.02	10.76	10.56	10.37	10.18	9.99	9.80	9.61	9.42	9.23	9.05	8.90
60%	10.95	10.67	10.47	10.27	10.06	9.86	9.67	9.47	9.27	9.07	8.88	8.72
65%	10.87	10.58	10.36	10.15	9.94	9.73	9.53	9.32	9.11	8.91	8.70	8.54
70%	10.78	10.47	10.25	10.03	9.81	9.59	9.38	9.16	8.95	8.73	8.52	8.35
75%	10.67	10.35	10.13	9.90	9.67	9.45	9.22	9.00	8.77	8.55	8.33	8.15
80%	10.55	10.23	9.99	9.76	9.52	9.29	9.06	8.83	8.60	8.36	8.13	7.95
85%	10.42	10.09	9.85	9.61	9.37	9.13	8.89	8.65	8.41	8.17	7.93	7.74
90%	10.29	9.95	9.70	9.45	9.21	8.96	8.71	8.47	8.22	7.97	7.73	7.53
95%	10.15	9.80	9.55	9.29	9.04	8.78	8.53	8.28	8.02	7.77	7.52	7.32
100%	9.99	9.64	9.38	9.12	8.86	8.60	8.34	8.08	7.82	7.56	7.30	7.10

(b) Electricity:

Ride-hailing demand	Ride-hailing battery electric vehicle stock % 2030: 12%	16%	19%	22%	26%	29%	32%	35%	38%	42%	45%	47%
	Ride-hailing battery electric vehicle sales % 2030: 18%	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**	**55%**	**60%**	**65%**	**70%**	**74%**
0.29%	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.87
5%	0.87	0.88	0.90	0.91	0.92	0.93	0.94	0.95	0.97	0.98	0.99	1.00
10%	0.88	0.91	0.93	0.95	0.97	1.00	1.02	1.04	1.06	1.09	1.11	1.13
15%	0.88	0.92	0.96	0.99	1.02	1.05	1.08	1.12	1.15	1.18	1.21	1.24
20%	0.88	0.94	0.98	1.02	1.06	1.10	1.14	1.19	1.23	1.28	1.33	1.36
25%	0.88	0.95	1.00	1.05	1.10	1.15	1.20	1.26	1.32	1.37	1.43	1.47
30%	0.87	0.95	1.01	1.07	1.13	1.20	1.26	1.32	1.39	1.45	1.52	1.57
35%	0.87	0.95	1.02	1.09	1.16	1.24	1.31	1.38	1.45	1.52	1.59	1.65
40%	0.86	0.96	1.03	1.11	1.19	1.27	1.35	1.43	1.51	1.58	1.66	1.72
45%	0.85	0.95	1.04	1.13	1.21	1.30	1.38	1.47	1.55	1.63	1.72	1.78
50%	0.83	0.95	1.05	1.14	1.23	1.32	1.41	1.50	1.59	1.68	1.77	1.84
55%	0.82	0.95	1.05	1.15	1.24	1.34	1.44	1.53	1.62	1.72	1.81	1.89
60%	0.80	0.95	1.05	1.15	1.25	1.35	1.45	1.55	1.65	1.75	1.85	1.93
65%	0.79	0.94	1.04	1.15	1.26	1.36	1.47	1.57	1.68	1.78	1.88	1.96
70%	0.77	0.93	1.04	1.15	1.26	1.37	1.48	1.59	1.69	1.80	1.91	2.00
75%	0.75	0.91	1.03	1.14	1.26	1.37	1.48	1.60	1.71	1.82	1.93	2.02
80%	0.74	0.90	1.02	1.14	1.25	1.37	1.49	1.60	1.72	1.84	1.95	2.05
85%	0.71	0.88	1.00	1.12	1.25	1.37	1.49	1.61	1.73	1.85	1.97	2.06
90%	0.69	0.86	0.99	1.11	1.24	1.36	1.49	1.61	1.73	1.86	1.98	2.08
95%	0.67	0.84	0.97	1.10	1.23	1.35	1.48	1.61	1.74	1.86	1.99	2.09
100%	0.64	0.82	0.95	1.08	1.21	1.34	1.47	1.60	1.74	1.87	2.00	2.10

- Significant reduction in gasoline consumption could be achieved when ride-hailing demand and BEVs penetration are high
- Increased vehicle electrification increases the electricity consumption

TECHNICAL ACCOMPLISHMENTS

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

Life cycle carbon emissions in 2030

Charging infrastructure fixed at existing conditions

Ride-hailing battery electric vehicle sales % 2030:

Ride-hailing demand	18%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	74%
0.29%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5%	2.1%	2.0%	1.9%	1.8%	1.7%	1.6%	1.6%	1.5%	1.4%	1.3%	1.3%	1.2%
10%	3.8%	3.6%	3.5%	3.3%	3.2%	3.0%	2.9%	2.7%	2.6%	2.4%	2.3%	2.2%
15%	5.2%	4.9%	4.7%	4.4%	4.2%	4.0%	3.8%	3.6%	3.4%	3.2%	3.0%	2.8%
20%	6.2%	5.8%	5.5%	5.3%	5.0%	4.7%	4.4%	4.2%	3.9%	3.6%	3.3%	3.1%
25%	6.9%	6.4%	6.1%	5.8%	5.4%	5.1%	4.8%	4.4%	4.1%	3.8%	3.5%	3.2%
30%	7.3%	6.8%	6.4%	6.0%	5.6%	5.2%	4.9%	4.5%	4.1%	3.7%	3.3%	3.0%
35%	7.5%	6.9%	6.5%	6.0%	5.6%	5.2%	4.7%	4.3%	3.9%	3.4%	3.0%	2.7%
40%	7.4%	6.8%	6.3%	5.8%	5.3%	4.9%	4.4%	3.9%	3.4%	2.9%	2.5%	2.1%
45%	7.2%	6.5%	5.9%	5.4%	4.9%	4.4%	3.9%	3.3%	2.8%	2.3%	1.8%	1.4%
50%	6.7%	6.0%	5.4%	4.8%	4.3%	3.7%	3.2%	2.6%	2.0%	1.5%	0.9%	0.5%
55%	6.1%	5.3%	4.7%	4.1%	3.5%	2.9%	2.3%	1.7%	1.1%	0.5%	-0.1%	-0.6%
60%	5.3%	4.5%	3.8%	3.2%	2.6%	1.9%	1.3%	0.7%	0.0%	-0.6%	-1.2%	-1.7%
65%	4.4%	3.5%	2.8%	2.2%	1.5%	0.8%	0.2%	-0.5%	-1.2%	-1.8%	-2.5%	-3.0%
70%	3.4%	2.4%	1.7%	1.0%	0.3%	-0.4%	-1.1%	-1.8%	-2.5%	-3.2%	-3.9%	-4.4%
75%	2.2%	1.2%	0.5%	-0.2%	-1.0%	-1.7%	-2.4%	-3.2%	-3.9%	-4.6%	-5.3%	-5.9%
80%	0.9%	-0.1%	-0.8%	-1.6%	-2.4%	-3.1%	-3.9%	-4.6%	-5.4%	-6.2%	-6.9%	-7.5%
85%	-0.4%	-1.5%	-2.3%	-3.1%	-3.9%	-4.6%	-5.4%	-6.2%	-7.0%	-7.8%	-8.6%	-9.2%
90%	-1.9%	-3.0%	-3.8%	-4.6%	-5.4%	-6.3%	-7.1%	-7.9%	-8.7%	-9.5%	-10.3%	-11.0%
95%	-3.5%	-4.6%	-5.4%	-6.3%	-7.1%	-7.9%	-8.8%	-9.6%	-10.5%	-11.3%	-12.1%	-12.8%
100%	-5.1%	-6.3%	-7.1%	-8.0%	-8.9%	-9.7%	-10.6%	-11.4%	-12.3%	-13.2%	-14.0%	-14.7%

With charging infrastructure growth

Ride-hailing battery electric vehicle sales % 2030:

Ride-hailing demand	18%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	74%
0.29%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
5%	1.2%	1.1%	1.0%	1.0%	0.9%	0.8%	0.7%	0.6%	0.6%	0.5%	0.4%	0.4%
10%	3.0%	2.8%	2.7%	2.5%	2.4%	2.2%	2.1%	1.9%	1.8%	1.6%	1.5%	1.4%
15%	4.4%	4.1%	3.9%	3.7%	3.5%	3.3%	3.0%	2.8%	2.6%	2.4%	2.2%	2.0%
20%	5.5%	5.1%	4.8%	4.5%	4.3%	4.0%	3.7%	3.4%	3.1%	2.8%	2.5%	2.3%
25%	6.2%	5.8%	5.4%	5.1%	4.8%	4.4%	4.1%	3.7%	3.3%	2.9%	2.6%	2.3%
30%	6.7%	6.1%	5.8%	5.4%	5.0%	4.5%	4.1%	3.7%	3.3%	2.9%	2.4%	2.1%
35%	6.9%	6.3%	5.9%	5.4%	4.9%	4.4%	4.0%	3.5%	3.0%	2.6%	2.1%	1.7%
40%	6.9%	6.2%	5.7%	5.2%	4.7%	4.2%	3.6%	3.1%	2.6%	2.1%	1.6%	1.2%
45%	6.7%	6.0%	5.4%	4.8%	4.2%	3.7%	3.1%	2.6%	2.0%	1.5%	0.9%	0.5%
50%	6.3%	5.5%	4.9%	4.3%	3.6%	3.1%	2.5%	1.9%	1.3%	0.7%	0.1%	-0.3%
55%	5.7%	4.8%	4.2%	3.5%	2.9%	2.3%	1.6%	1.0%	0.4%	-0.2%	-0.8%	-1.3%
60%	5.0%	4.0%	3.4%	2.7%	2.0%	1.4%	0.7%	0.0%	-0.6%	-1.3%	-1.9%	-2.4%
65%	4.1%	3.1%	2.4%	1.7%	1.0%	0.3%	-0.4%	-1.1%	-1.7%	-2.4%	-3.1%	-3.6%
70%	3.1%	2.1%	1.3%	0.6%	-0.1%	-0.8%	-1.5%	-2.3%	-3.0%	-3.7%	-4.4%	-5.0%
75%	2.0%	0.9%	0.2%	-0.6%	-1.3%	-2.1%	-2.8%	-3.6%	-4.3%	-5.0%	-5.8%	-6.4%
80%	0.7%	-0.3%	-1.1%	-1.9%	-2.7%	-3.4%	-4.2%	-5.0%	-5.7%	-6.5%	-7.3%	-7.9%
85%	-0.6%	-1.7%	-2.5%	-3.3%	-4.1%	-4.9%	-5.7%	-6.5%	-7.3%	-8.1%	-8.8%	-9.5%
90%	-2.0%	-3.1%	-4.0%	-4.8%	-5.6%	-6.4%	-7.2%	-8.1%	-8.9%	-9.7%	-10.5%	-11.2%
95%	-3.5%	-4.7%	-5.5%	-6.4%	-7.2%	-8.0%	-8.9%	-9.7%	-10.6%	-11.4%	-12.2%	-12.9%
100%	-5.1%	-6.3%	-7.1%	-8.0%	-8.9%	-9.7%	-10.6%	-11.4%	-12.3%	-13.2%	-14.0%	-14.7%

- % reduction in carbon emissions is similar to the percentage reduction in energy consumption
- Carbon emissions include emissions from upstream and vehicle use

RESPONSES TO PREVIOUS YEARS REVIEWERS COMMENTS

- Building on the available data leaves many potential errors that cannot be quantified. For example, determining charging availability (0.25- mile x 0.25-mile grid cells) using data which includes Level 2 chargers, does not seem appropriate to determine charging availability for ride hailing scenarios.

Charging availability defined using existing data is only to show the percentage of trips can be charged at their destination (Assuming destination charge). When we consider the charging time and potential queue build up at the charger due to ride hailing, we used DCFC charging time and shorter waiting time.

- The project has progressed, in spite of the difficulty in aggregating results to the national level…The reviewer suggested more sensitivity work should be a priority in light of the sparsity of actual data supporting developing analyses at the national level

We thank reviewers for the recognition and suggestions. We prioritized sensitivity analysis in FY19 by varying ride-hailing demand and share of BEVs in the ride-hailing fleet, and quantified the range of resulting energy consumption and carbon emissions. Selected results are presented in this presentation.

- The reviewer suggested considering the impact of cost of charging analysis public versus home/private and its sensitivity bearing on charge availability

We thank reviewers for the recognition and suggestions. We agree the impact of cost of charging public versus home/private and its sensitivity would affect the charge availability. However, that is out of our study scope. We suggested it in the future research steps.

RESPONSES TO PREVIOUS YEARS REVIEWERS COMMENTS

- The reviewer suggested that care should be taken to recognize the limitations and uncertainties associated with these models (e.g. EVI-Pro), and the potential for the effects of these uncertainties to propagate to the national level.

We recognized that limitations of using bottom-up approach, which relies on simulation models like EVI-Pro. The simulation results are region-specific and lacks generalizability to other regions or aggregation to a higher geographical level. Those models are also subject to data availability of detailed real-world trip data or travel survey data with origin-destination information.

That is the exactly the reason we developed the top-down approach and compared the results of the two different approaches. Results from the two different approaches are in general agreement, differing by less than 5%. Results from top-down approach is presented in this presentation.

- The reviewer said that for any future work the project team should consider determining the uncertainties of existing results as important as generating additional results.

We thank reviewers for the good suggestion. We agree the importance of identifying the uncertainties. We have identified some of them in FY19 and documented in the final report. For example, how dead heading miles change with ride hailing demand was uncertain when we did the study. Not many simulation results were available for us to cite. We will continue to highlight those uncertainties and replace them with better data when they become available.

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

- Argonne National Laboratory (Lead)
  - Collaborate on scenario definition
  - Lead data collection, processing and scenarios design
  - National scenario analysis
  - Draft report and journal submissions
- NREL
  - Collaborate on scenario definition
  - Provide regional simulation results
  - Collaborate on report drafting
- ORNL
  - Collaborate on scenario definition
  - Collaborate on national scenario analysis
  - Collaborate on report and journal paper drafting

REMAINING CHALLENGES AND BARRIERS

- Data availability for understanding charging opportunities for both ride-hailing and private travel
  - Trip origin and destination data are needed
  - More cities need to be studied to approve the general relationship between charging availability and opportunities
  - % of dead heading miles and how that change with different ride hailing demand
- Sensitivity of results to the assumptions about BEV electric range and # of ride-hailing trips/day/vehicle in simulations
- Uncertainties in the key assumptions, such as future vehicle and charging technology performances, ride hailing demand, and infrastructure availabilities
- Further cross-validation between bottom-up (simulation) and top-down (mathematical probability) approaches.

PROPOSED FUTURE RESEARCH BEYOND THIS PROJECT

Note: Any proposed future work is subject to funding levels

- Quantify cost of charging, public versus home/private, and their impacts on the charge possibilities
- Consider changes in vehicle ownership and total vehicle miles traveled due to ride-hailing
  - Ride-hailing could affect the traditional private vehicle ownership
  - Ride-hailing could induce more travel due to convenience
- Sensitivity analysis on the key uncertainties in assumptions, especially those related to DOE VTO R&D programs
  - Synergies between adoption of electrification and ride-hailing
  - Mixes of different charging technologies and their impacts on vehicle adoption
  - Ride-hailing daily travel pattern: % of full time drivers, average rider ship, etc.
- Compare and validate the results from top-down approach with those of different simulation models

SUMMARY

- This study 1) developed decision-making framework that estimates required charging infrastructure in an urban area to support electric ride-hailing operations, and 2) quantify the resulting energy and emission impacts due to **ride-hailing, electrification, and charging infrastructure** separately and together
- FY 19 focus on the top-down approach which draw probability and statistics from national available travel survey data
- Reduction in national petroleum consumption is due to the impact of both improved **charging infrastructure availability** and **increased BEV ride-hailing**
  - Improved charging availability and charging power significantly induces PEV adoption and increases eVMT
  - Increased ride-hailing demand enables faster vehicle turnover rate so the fleet average fuel efficiency is improved
- Charging infrastructure alone only reduce petroleum consumption by 1%–2%, while faster fleet turn-over (due to ride-hailing) and BEV penetration can bring 18% reduction

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MOBILITY FOR OPPORTUNITY

FOR MORE INFORMATION

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TECHNICAL BACKUP SLIDES

RESULTS: IMPACT OF CHARGING INFRASTRUCTURE

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These figures shows: impact of infrastructure alone is small, about 1-2%

Energy:

Charging infrastructure fixed at existing conditions

Ride-hailing demand	Ride-hailing battery electric vehicle sales % 2030: 18%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	74%	Personal-use BEV sales share
0.29%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	32.4%
5%	2.1%	1.9%	1.8%	1.7%	1.6%	1.5%	1.4%	1.3%	1.2%	1.1%	1.0%	0.9%	32.4%
10%	3.8%	3.5%	3.3%	3.1%	2.9%	2.7%	2.5%	2.3%	2.1%	1.9%	1.7%	1.6%	32.4%
15%	5.2%	4.8%	4.5%	4.2%	3.9%	3.6%	3.3%	3.0%	2.7%	2.4%	2.1%	1.9%	32.4%
20%	6.2%	5.7%	5.3%	4.9%	4.5%	4.2%	3.8%	3.4%	3.0%	2.7%	2.3%	2.0%	32.4%
25%	6.9%	6.3%	5.8%	5.4%	4.9%	4.5%	4.0%	3.6%	3.1%	2.7%	2.2%	1.8%	32.4%
30%	7.3%	6.6%	6.1%	5.5%	5.0%	4.5%	4.0%	3.5%	2.9%	2.4%	1.9%	1.5%	32.4%
35%	7.5%	6.7%	6.1%	5.5%	4.9%	4.3%	3.7%	3.1%	2.6%	2.0%	1.4%	0.9%	32.4%
40%	7.4%	6.5%	5.9%	5.2%	4.6%	3.9%	3.3%	2.6%	2.0%	1.3%	0.7%	0.2%	32.4%
45%	7.2%	6.2%	5.5%	4.8%	4.1%	3.4%	2.7%	2.0%	1.2%	0.5%	-0.2%	-0.7%	32.4%
50%	6.7%	5.7%	4.9%	4.2%	3.4%	2.6%	1.9%	1.1%	0.3%	-0.4%	-1.2%	-1.8%	32.4%
55%	6.1%	5.0%	4.2%	3.4%	2.6%	1.8%	0.9%	0.1%	-0.7%	-1.5%	-2.3%	-3.0%	32.4%
60%	5.4%	4.2%	3.3%	2.5%	1.6%	0.7%	-0.1%	-1.0%	-1.9%	-2.7%	-3.6%	-4.3%	32.4%
65%	4.5%	3.2%	2.3%	1.4%	0.5%	-0.4%	-1.3%	-2.2%	-3.2%	-4.1%	-5.0%	-5.7%	32.4%
70%	3.4%	2.1%	1.2%	0.2%	-0.7%	-1.7%	-2.6%	-3.6%	-4.5%	-5.5%	-6.5%	-7.2%	32.4%
75%	2.3%	0.9%	-0.1%	-1.1%	-2.1%	-3.1%	-4.1%	-5.1%	-6.0%	-7.0%	-8.0%	-8.8%	32.4%
80%	1.0%	-0.4%	-1.4%	-2.5%	-3.5%	-4.5%	-5.6%	-6.6%	-7.6%	-8.7%	-9.7%	-10.5%	32.4%
85%	-0.4%	-1.8%	-2.9%	-4.0%	-5.0%	-6.1%	-7.2%	-8.2%	-9.3%	-10.4%	-11.5%	-12.3%	32.4%
90%	-1.8%	-3.3%	-4.4%	-5.5%	-6.6%	-7.8%	-8.9%	-10.0%	-11.1%	-12.2%	-13.3%	-14.2%	32.4%
95%	-3.4%	-4.9%	-6.1%	-7.2%	-8.3%	-9.5%	-10.6%	-11.8%	-12.9%	-14.0%	-15.2%	-16.1%	32.4%
100%	-5.0%	-6.6%	-7.8%	-8.9%	-10.1%	-11.3%	-12.5%	-13.6%	-14.8%	-16.0%	-17.2%	-18.1%	32.4%

Energy:

With charging infrastructure growth

Ride-hailing demand	Ride-hailing battery electric vehicle sales % 2030: 18%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	74%	Personal-use BEV sales share
0.29%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%	[43.8% , 43.8%]
5%	0.9%	0.7%	0.6%	0.5%	0.4%	0.3%	0.2%	0.1%	0.0%	-0.1%	-0.2%	-0.3%	[43.8% , 43.8%]
10%	2.7%	2.4%	2.2%	2.0%	1.8%	1.6%	1.4%	1.2%	1.0%	0.8%	0.6%	0.4%	[43.8% , 43.8%]
15%	4.1%	3.7%	3.4%	3.1%	2.8%	2.5%	2.3%	2.0%	1.7%	1.4%	1.1%	0.9%	[43.8% , 43.8%]
20%	5.2%	4.7%	4.3%	3.9%	3.6%	3.2%	2.8%	2.4%	2.0%	1.6%	1.2%	0.8%	[43.8% , 45.4%]
25%	5.9%	5.3%	4.9%	4.4%	4.0%	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%	0.6%	[43.8% , 46.8%]
30%	6.4%	5.7%	5.2%	4.7%	4.1%	3.5%	3.0%	2.4%	1.8%	1.2%	0.7%	0.2%	[43.8% , 47.9%]
35%	6.7%	5.9%	5.3%	4.7%	4.0%	3.3%	2.7%	2.1%	1.4%	0.8%	0.2%	-0.4%	[43.8% , 48.8%]
40%	6.7%	5.8%	5.1%	4.4%	3.7%	3.0%	2.3%	1.6%	0.9%	0.2%	-0.5%	-1.1%	[43.8% , 49.5%]
45%	6.5%	5.5%	4.7%	4.0%	3.2%	2.4%	1.7%	0.9%	0.2%	-0.6%	-1.3%	-1.9%	[43.8% , 50.1%]
50%	6.1%	5.0%	4.2%	3.4%	2.5%	1.7%	0.9%	0.1%	-0.7%	-1.5%	-2.3%	-2.9%	[43.8% , 50.5%]
55%	5.6%	4.4%	3.5%	2.6%	1.8%	0.9%	0.0%	-0.8%	-1.6%	-2.5%	-3.3%	-4.0%	[43.8% , 51.0%]
60%	4.9%	3.6%	2.7%	1.8%	0.8%	-0.1%	-1.0%	-1.8%	-2.7%	-3.6%	-4.5%	-5.2%	[43.8% , 51.2%]
65%	4.0%	2.7%	1.7%	0.8%	-0.2%	-1.1%	-2.1%	-3.0%	-3.9%	-4.9%	-5.8%	-6.5%	[44.0% , 51.3%]
70%	3.0%	1.6%	0.6%	-0.3%	-1.3%	-2.3%	-3.3%	-4.3%	-5.2%	-6.2%	-7.2%	-7.9%	[44.5% , 51.5%]
75%	1.9%	0.5%	-0.5%	-1.6%	-2.6%	-3.6%	-4.6%	-5.6%	-6.6%	-7.6%	-8.6%	-9.4%	[44.9% , 51.6%]
80%	0.7%	-0.7%	-1.8%	-2.9%	-3.9%	-5.0%	-6.0%	-7.1%	-8.1%	-9.2%	-10.2%	-11.0%	[45.3% , 51.7%]
85%	-0.6%	-2.1%	-3.2%	-4.3%	-5.4%	-6.4%	-7.5%	-8.6%	-9.7%	-10.8%	-11.8%	-12.7%	[45.6% , 51.8%]
90%	-2.0%	-3.5%	-4.6%	-5.7%	-6.9%	-8.0%	-9.1%	-10.2%	-11.3%	-12.4%	-13.5%	-14.4%	[46.0% , 51.9%]
95%	-3.5%	-5.0%	-6.2%	-7.3%	-8.5%	-9.6%	-10.7%	-11.9%	-13.0%	-14.2%	-15.3%	-16.2%	[46.3% , 52.0%]
100%	-5.0%	-6.6%	-7.8%	-8.9%	-10.1%	-11.3%	$\boxed{-12.5\%}$	-13.6%	-14.8%	-16.0%	-17.2%	-18.1%	[46.7% , 52.0%]

Results from the bottom-up approach (slide 24) shows 16.5% reduction. The difference is less than 5%.

BOTTOM UP VS. TOP DOWN APPROACHES

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Bottom-up approach

- Model the deployment of charging infrastructure based on temporal and spatial distribution of travel and resulting charging demand

Issues of bottom-up approaches

- **region-specific simulation** and results lack generalizability to other regions or aggregation to a higher geographical level, i.e., national level;
- Requires significant amount of **time and computation effort,** depending on network complexity;
- **subject to data availability** of detailed real-world trip data or travel survey data with origin-destination information.

Top-down approach

- Mathematically identify the number of chargers needed with a given ride-hailing BEV fleet size and charging demand, **based on probability and statistics**, using national available travel and census data

Advantages of top-down approach

- Not restricted to regional simulation results which are subject to data availability
- Analyze the infrastructure requirement at the national level robustly
- Faster and less computation costs

RESULTS FROM BOTTOM-UP APPROACH (FY17-18 WORK)

(High Ride hailing Case, 150 kW Public Charging, Urban Only)